Submarine Ground-Water Discharge in Upper Indian River Lagoon, Florida

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Abstract

The discharge of submarine groundwater has recently been shown to be an important process in many environmentally fragile coastal ecosystems. However, groundwater discharge into coastal bottom water is still an often-overlooked component of many hydrologic and oceanic models. The exchange of interstitial water across the sediment/water interface may introduce anthropogenic pollutants, may be an important part of coastal nutrient cycles, and may cause excess nutrient loading, thereby potentially degrading the coastal water quality. Here we report on Year-1 results from a co-operative (USGS-UF-LSU) project that is investigating the role of submarine groundwater discharge into Indian River Lagoon, Florida.

INTRODUCTION

The Indian River Lagoon system extends over 250 km along the east-central coast of Florida and consists of three inter-connected lagoonal basins: Mosquito, Banana River, and Indian River lagoons. Exchange of lagoon water with the Atlantic Ocean is limited to four tidal inlets (Sebastian, Ft. Pierce, St. Lucie and Jupiter) that occur in the southern part of Indian River Lagoon. Precipitation, the exchange of water through these inlets, wind, tidal forcing, evaporation, surface runoff, and potential submarine groundwater discharge control the salinity of lagoon water. In this system, the intensity and duration of wind have the most pronounced affect on lagoon water levels. The overall objective of this project was to determine the rate and potential ecological significance of submarine groundwater discharge (Table 1) to Indian River Lagoon.

The study area during the first year of the project included the northern most 10 km of the Indian River Lagoon (~48 km^2). Of the 28 sampling stations, 22 were arranged in shore-perpendicular transects; the remaining six stations were distributed within the lagoon center (Fig. 1). At each station, lagoon and interstitial water samples were collected, and groundwater seepage rates were measured using conventional seepage meters. Interstitial water samples were obtained from four stations using custom-built multi-samplers. Six groundwater samples were collected from wells surrounding the lagoon. Two additional samples were collected from tributaries to the lagoon including Turnbull Creek and Haulover Canal. Sampling of the seepage stations, groundwater wells, and tributaries occurred in May 1999, to coincide with the end of the normal dry season, and in August 1999, during the normal rainy season. A third trip in December 1999 was used only to sample interstitial water.

Table 1. Factors that affect submarine groundwater discharge.

Hydrogeology

The hydrogeology along the northeastern coast of Florida can be broadly divided into two aquifer systems: the Surficial and the Floridan aquifer system. Sand, silt and clays of the Intermediate confining unit, which constitutes most of the Hawthorn Formation, separates these two aquifer systems (Leve, 1970; Spechler, 1994). The Surficial

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Figure 1. Site location map for upper Indian River Lagoon, Florida.

aquifer system consists of Miocene to Holocene interbedded sand, shell, silt, clay and dolomitic limestone strata. The Surficial aquifer system is mostly unconfined, although the hydrogeology can be very heterogeneous. Four clastic, very regional surficial aquifers border the Indian River Lagoon including Terrace, Atlantic Coastal Ridge, Ten-mile Ridge, and Inter-ridge. Terrace aquifer occurs on the barrier islands separating Indian River Lagoon from the Atlantic Ocean. The Atlantic Coastal Ridge occurs on the western bank of Indian River Lagoon, in the northern reaches of the lagoon. This aquifer is composed of the Pleistocene Anastasia Formation, and provides most of the water supply for towns on the western edge of the northern Indian River Lagoon (Mims and Titusville). The Floridan aquifer system can be further divided into two water-bearing aquifers (Upper and Lower Floridan), separated by less permeable semi-confining units. The Upper Floridan aquifer in the study area corresponds to the Ocala Limestone and in some parts, the Avon Park Formation. The Ocala Limestone is characterized by high permeabilities that can be enhanced along bedding planes, fractures, and conduits.

Significant variations in ground-water levels occur seasonally (Fig. 2). Superimposed on such seasonal variations is a long-term decrease in the potentiometric surface that is largely attributed to increased groundwater withdrawals (Fig. 3). Nonetheless, recent potentiometric surface maps of the Upper Floridan aquifer indicate elevations that are above sea level for the entire length of Indian River Lagoon. Such potentiometric surface elevations increase from north to south, where the Hawthorn Formation increases in thickness. The elevated potentiometric surface of the Upper Floridan, combined with the general lack of a confining unit in the vicinity of the study area makes much of Indian River Lagoon a potential zone of submarine groundwater discharge.

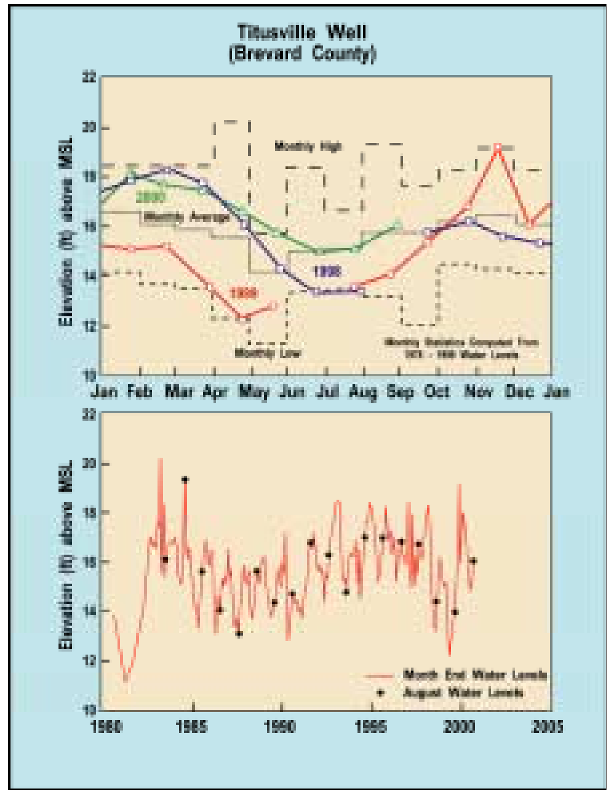

Figure 2. Hydrograph of a Titusville well (adapted from St. John's River Water Management District, 2000).

Geochemistry

To derive estimates of ground-water seepage into Indian River lagoon, the following suite of tracers, chemical constituents and sampling devices were measured or utilized: nutrients, Cl^-, conductivity, pH, temperature, dissolved oxygen, $^{87}Sr/^{86}Sr$, $\delta^{18}O$, $^{223,224,226}Ra$, ^{222}Rn, seep meters, multi-samplers, and benthic flux chambers (Martin et al., 2000). Seepage rates were spatially and temporally heterogeneous, yet similar to rates previously measured in Indian River Lagoon using identical techniques. The seepage rates ranged from 3 - 100 ml m^{-2} min^{-1} during May (dry season) to 22 - 144 ml m^{-2} min^{-1} during August (rainy season). The average value for all meters increased from 40 to 63 ml m^{-2} min^{-1} from the dry to the rainy season, implying that there may be a connection between rainfall and increased seepage rates. The heterogeneous nature of these rates is likely caused by fluctuations in sediment permeabilities and other geologic characteristics.

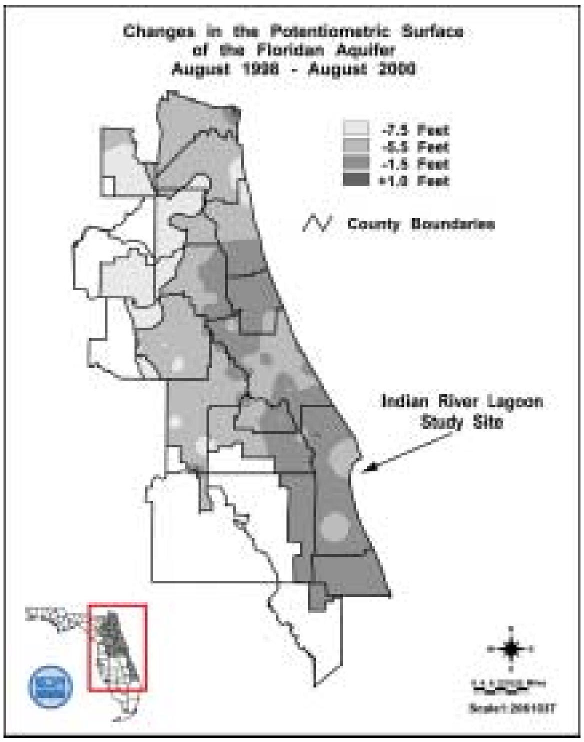

Figure 3. Potentiometric change map (adapted from St. John's River Water Management District, 2000).

Geochemistry

Radon-222 and Ra isotopes have previously provided regionally integrated estimates of seepage flux in varied coastal environments (Cable et al., 1996; Moore, 1999; Swarzenski et al., in press). Benthic fluxes of Ra to the Indian River Lagoon are calculated using three independent methods that rely on the activities of short-lived Ra isotopes: 1) lagoon budget, 2) benthic flux chambers and 3) pore-water modeling (Fig. 4). The first two methods yield direct measurements of flux across the sediment/water interface, whereas the third technique generates an indirect flux estimate on the basis of pore-water Ra profiles. Calculations of the benthic flux of Ra range up to almost 500 dpm m^{-2} day^{-1}. Using ^{226}Ra pore-water activities, a maximum upward subsurface water flow of about 5 - 17 cm day^{-1} is required to sustain these fluxes. These values are similar to the values measured directly with the seepage meters.

By using ^{222}Rn and ^{226}Ra as mass balance tracers of seepage flux to the northern Indian River Lagoon it is possible to obtain measurements of seepage that are independent of the short-lived Ra isotopes. Assumptions required for this mass balance approach are that negligible effects were observed from surface water exchange to the lagoon, tides, and diffusion from the sediments. Analogous to the short-lived Ra isotopes, seepage fluxes measured on the basis of excess ^{226}Ra activities are similar in magnitude to those estimated using seepage meters. Each submarine groundwater discharge technique has individual strengths and weaknesses.

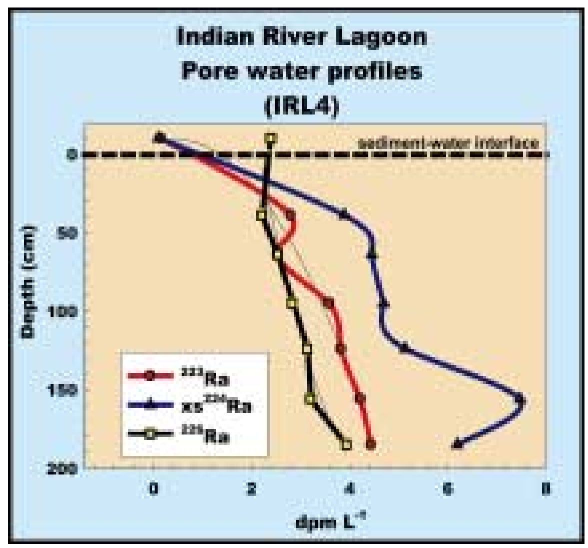

Figure 4. Interstitial radium activities at Station IRL 4, upper Indian River Lagoon.

Seepage meters provide a direct measurement of localized flow. They can also easily provide 'clean' seep water samples. However, seep meters may be susceptible to possible artifacts caused by interaction of tides and waves, although such limitations have not been thoroughly tested.

The radioisotopes are less difficult to sample in the field than using seepage meters, but their measurement requires sophisticated laboratory equipment that is not widely available. One important characteristic of the radioisotope techniques is that they provide an integrated value of seepage rates across the entire lagoon. They are thus complementary to the seepage meter technique.

Chloride concentrations indicate that only a minor component (1 - 5%) of seep water originates from meteoric groundwater. This implies that 95 - 99% of the interstitial water has to be recycled lagoon seawater. The isotopic concentration of strontium ($^{87}Sr/^{86}Sr$) was nearly identical in the seep water and lagoon water, yet was measurably lower than that in modern seawater. The $^{87}Sr/^{86}Sr$ ratios were also systematically lower during the rainy season, reflecting the greater influx of seep water into lagoon water and short groundwater residence times. Nutrient concentrations were 3 to 5 times elevated in the seep water over the lagoon water, and suggest that sediment/water interface exchange processes, such as submarine groundwater discharge, are critical components of coastal nutrient budgets (Johannes, 1980; Krest et al., 2000).

SUMMARY

The hydrogeologic framework of northeastern Florida indicates that the Hawthorn confining unit is thinnest or absent in the vicinity of upper Indian River Lagoon. This feature might imply a vigorous hydrologic exchange between the Floridan and the Surficial aquifer systems that may extend into Indian River Lagoon in the form of submarine groundwater discharge.

Conservative solutes such as Sr isotopes and Cl^- concentrations, however, suggest that only a very small fraction (1 - 5%) of interstitial water is composed of meteoric groundwater. Therefore, almost all of the interstitial water must consist of recycled seawater. A combination of seep meters and naturally occurring isotopes (Ra and Rn) produced seepage rates that are generally in close agreement with one another. The observed 5-fold variation in seepage rates can be attributed to fundamental differences in each technique.

REFERENCES

Cable, J.E., Bugna, G.C., Burnett, W.C., Chanton, J.P., 1996, *Application of ^{222}Rn and CH_4 for assessment of groundwater discharge to the coastal ocean.* Limnology and Oceanography v. 41, pp. 1347-1353.

Johannes, R.E., 1980, *The ecological significance of the submarine discharge of groundwater.* Marine Ecology Progress Series, v. 3, pp. 365-373.

Krest, J.M., Moore W.S., Gardner L.R., Morris J.T., 2000. *Marsh nutrient export supplied by groundwater discharge: Evidence from radium measurements.* Global Biogeochemical Cycles, v. 14, pp.167-176.

Leve, G.W., 1970, *The Floridan aquifer in Northeast Florida.* Groundwater, v. 6, pp. 19-29.

Martin, J.B., Cable, J.E., Swarzenski, P.W., 2000, *Quantification of groundwater discharge and nutrient loading to the Indian River Lagoon.* St. Johns River Water Management District Report pp. 154.

Moore, W.S., 1999, *The subterranean estuary: A reaction zone of groundwater and seawater.* Marine Chemistry, v. 65, pp. 111-125.

St. John’s River Water Management District, 2000, August 2000 Hydrologic Conditions Report, pp. 71.

Spechler, R.M., 1994, *Saltwater intrusion and the quality of water in the Floridan Aquifer system, northeastern Florida.* U.S. Geological Survey Water Resources Invest. Report 92-4174, pp. 76.

Swarzenski, P.W., Reich, C.D., Spechler, R.M., Kindinger, J.L. and Moore, W.S. *Using multiple geochemical tracers to characterize the hydrogeology of the submarine spring off Crescent Beach, Florida.* Chemical Geology, (in press).